US009065538B2

(12) **United States Patent**
Shirakata et al.

(10) **Patent No.: US 9,065,538 B2**
(45) **Date of Patent: Jun. 23, 2015**

(54) **TRANSMISSION-RECEPTION DEVICE**

(75) Inventors: **Naganori Shirakata**, Kanagawa (JP); **Tadashi Morita**, Kanagawa (JP)

(73) Assignee: **Panasonic Corporation**, Osaka (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 203 days.

(21) Appl. No.: **13/814,914**

(22) PCT Filed: **Jan. 31, 2012**

(86) PCT No.: **PCT/JP2012/000648**

§ 371 (c)(1),
(2), (4) Date: **Feb. 7, 2013**

(87) PCT Pub. No.: **WO2012/132185**

PCT Pub. Date: **Oct. 4, 2012**

(65) **Prior Publication Data**

US 2013/0157589 A1 Jun. 20, 2013

(30) **Foreign Application Priority Data**

Mar. 30, 2011 (JP) 2011-075832

(51) **Int. Cl.**
H04B 1/10 (2006.01)
H04B 1/40 (2015.01)
H04L 27/26 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04B 1/40*** (2013.01); ***H04L 27/2636*** (2013.01); ***H04L 25/068*** (2013.01); *H04L 27/32* (2013.01); ***H04L 27/367*** (2013.01)

(58) **Field of Classification Search**
CPC H04B 1/0475; H04B 1/10; H04B 1/44
USPC 455/63.1, 296, 114.2
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,612,978 A * 3/1997 Blanchard et al. 375/350
7,133,825 B2 * 11/2006 Bou-Ghazale 704/233
(Continued)

FOREIGN PATENT DOCUMENTS

JP 2000-244370 A 9/2000
JP 2007-195056 A 8/2007
JP 2010-252178 A 11/2010

OTHER PUBLICATIONS

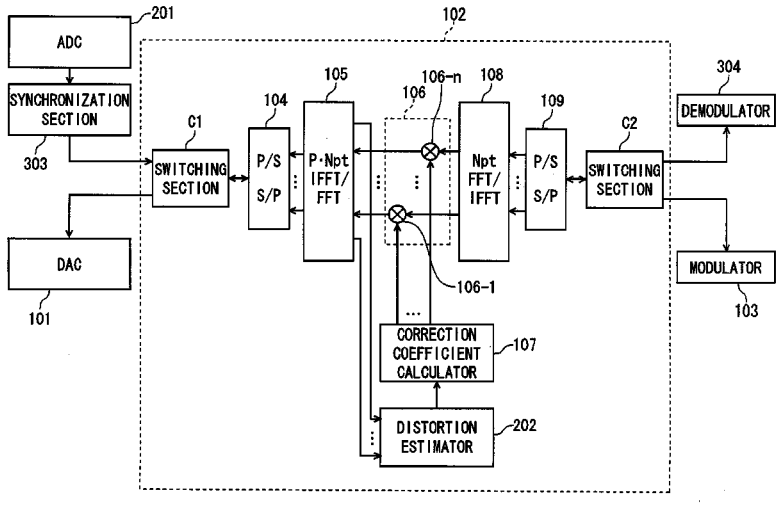
International Search Report, mailed May 1, 2012, for International Application No. PCT/JP2012/000648, 2 pages.

Primary Examiner — Wen Huang
(74) *Attorney, Agent, or Firm* — Seed IP Law Group PLLC

(57) **ABSTRACT**

A transmission-reception device includes a radio frequency section that performs a frequency conversion on a signal which is modulated using a single carrier transmission system, a correction coefficient multiplier that multiplies a frequency domain signal by a distortion correction coefficient in the frequency conversion of the radio frequency section to correct a distortion, a first transformer that converts a time domain signal into a frequency domain signal at a time of reception, and converts the frequency domain signal which is distortion-corrected by the correction coefficient multiplier into a time domain signal at a time of transmission, and a second transformer that converts a time domain signal into a frequency domain signal at a time of transmission, and converts the frequency domain signal which is distortion-corrected by the correction coefficient multiplier into a time domain signal at a time of reception.

6 Claims, 8 Drawing Sheets



(51) **Int. Cl.**

H04L 25/06	(2006.01)
H04L 27/36	(2006.01)
H04L 27/32	(2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,333,423	B2 *	2/2008	Palaskas et al.	370/210
7,548,589	B2 *	6/2009	Kim	375/267
7,894,556	B2 *	2/2011	Casabona et al.	375/346
8,085,878	B2 *	12/2011	Choi et al.	375/326
2006/0135211	A1 *	6/2006	Chae et al.	455/562.1
2009/0227278	A1 *	9/2009	Cho et al.	455/522
2010/0297969	A1 *	11/2010	Miyoshi et al.	455/127.1

* cited by examiner

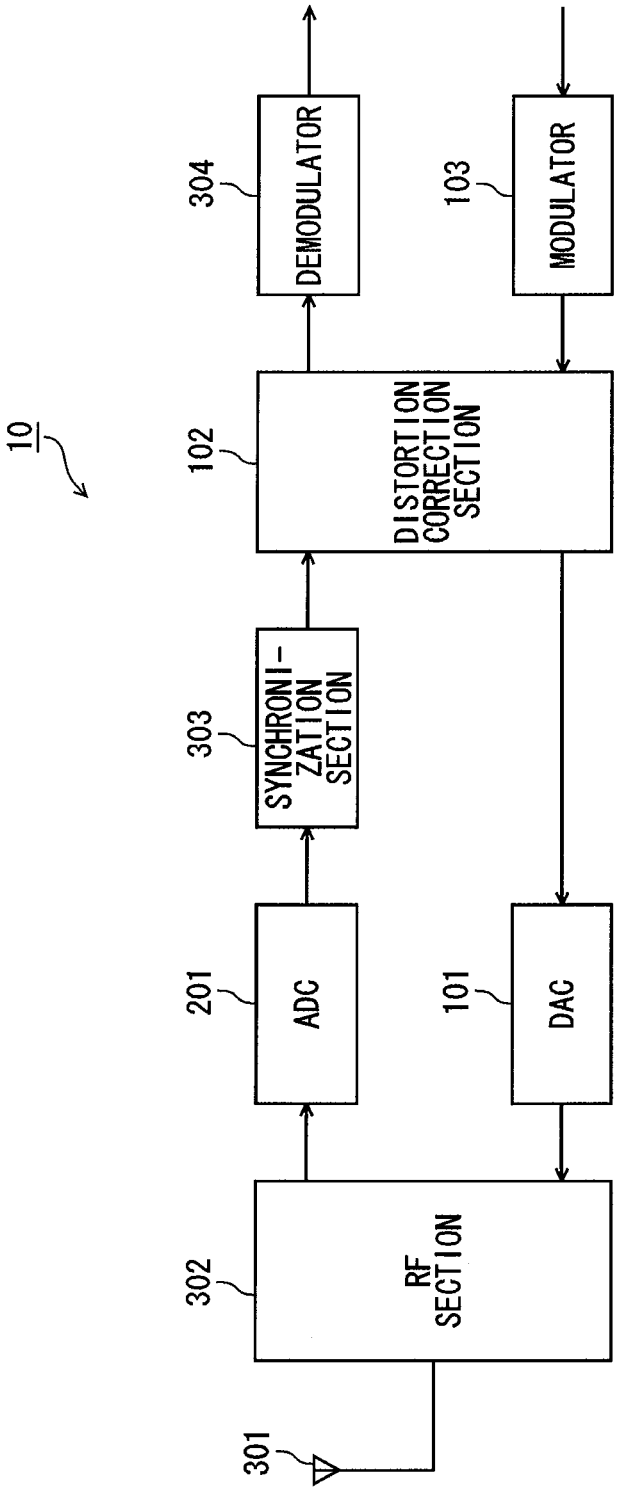

10
301
302
RF SECTION
201
ADC
303
SYNCHRONI-ZATION SECTION
102
DISTORTION CORRECTION SECTION
304
DEMODULATOR
101
DAC
103
MODULATOR

FIG. 1

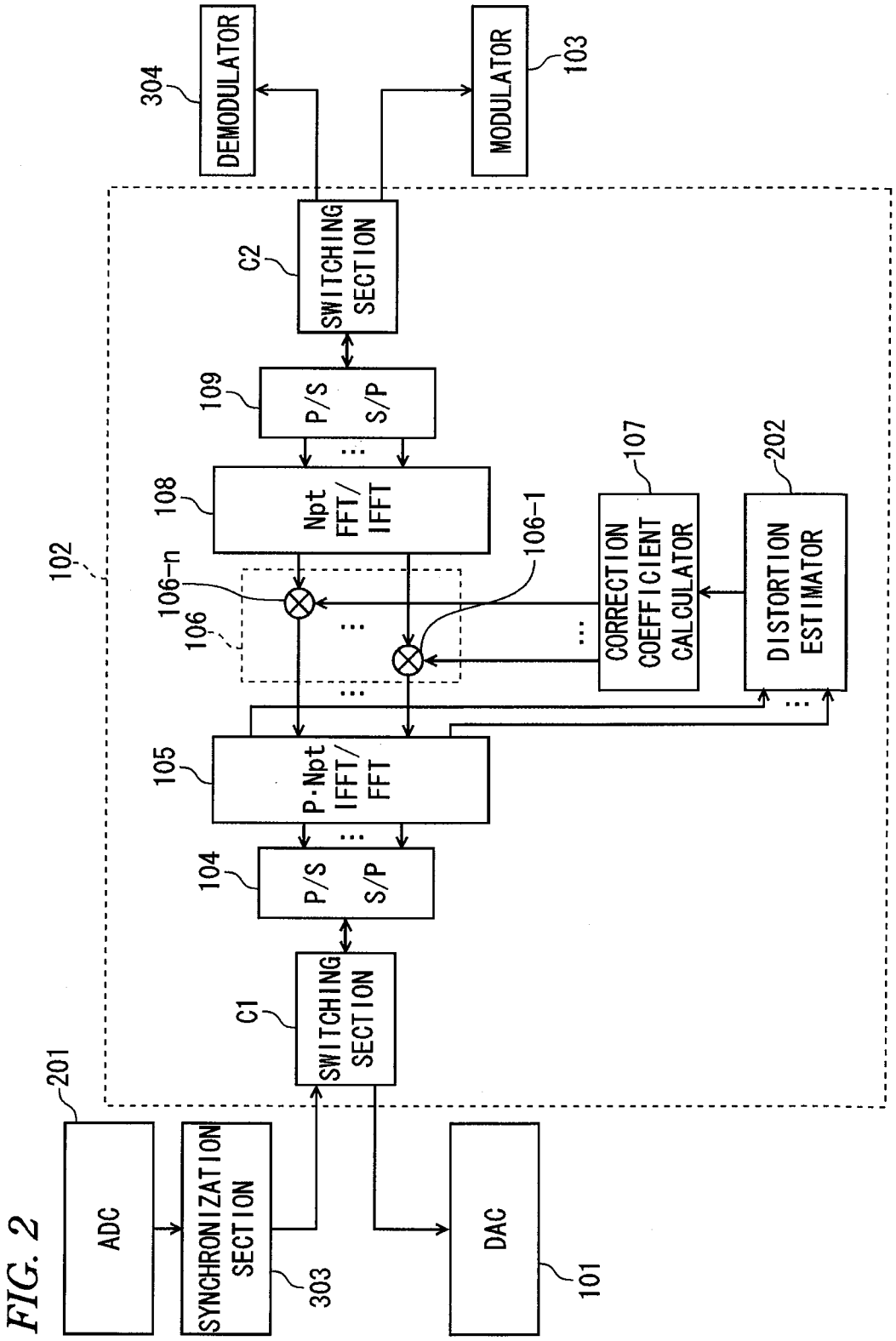

DEMODULATOR
304
MODULATOR
103
SWITCHING SECTION
C2
P/S
S/P
109
Npt FFT/ IFFT
108
102
106-n
106
106-1
CORRECTION COEFFICIENT CALCULATOR
107
DISTORTION ESTIMATOR
202
P·Npt IFFT/ FFT
105
P/S
S/P
104
SWITCHING SECTION
C1
201
ADC
SYNCHRONIZATION SECTION
303
DAC
101

FIG. 2

FIG. 3

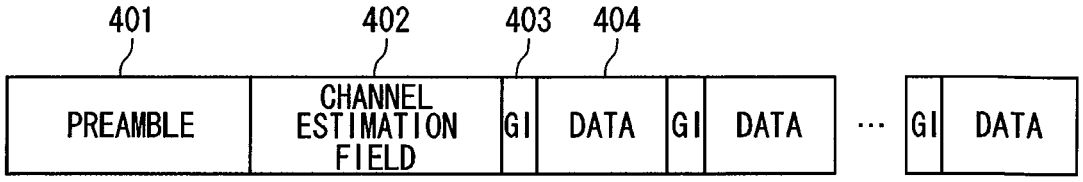

401
402
403
404
PREAMBLE
CHANNEL ESTIMATION FIELD
GI
DATA
GI
DATA
...
GI
DATA

FIG. 4

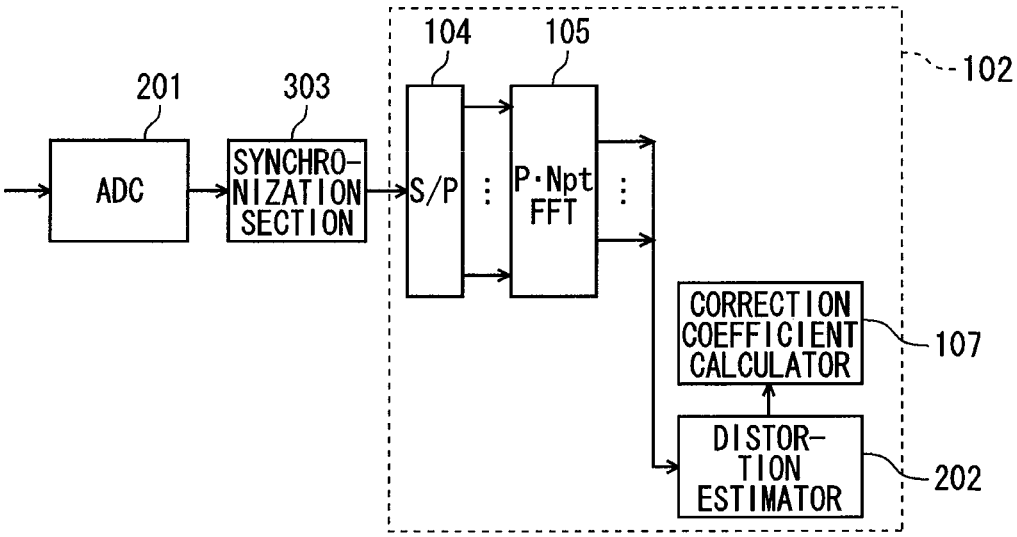

104
105
102
201
303
ADC
SYNCHRO-
NIZATION
SECTION
S/P
P·Npt
FFT
CORRECTION
COEFFICIENT
CALCULATOR
107
DISTOR-
TION
ESTIMATOR
202

FIG. 5

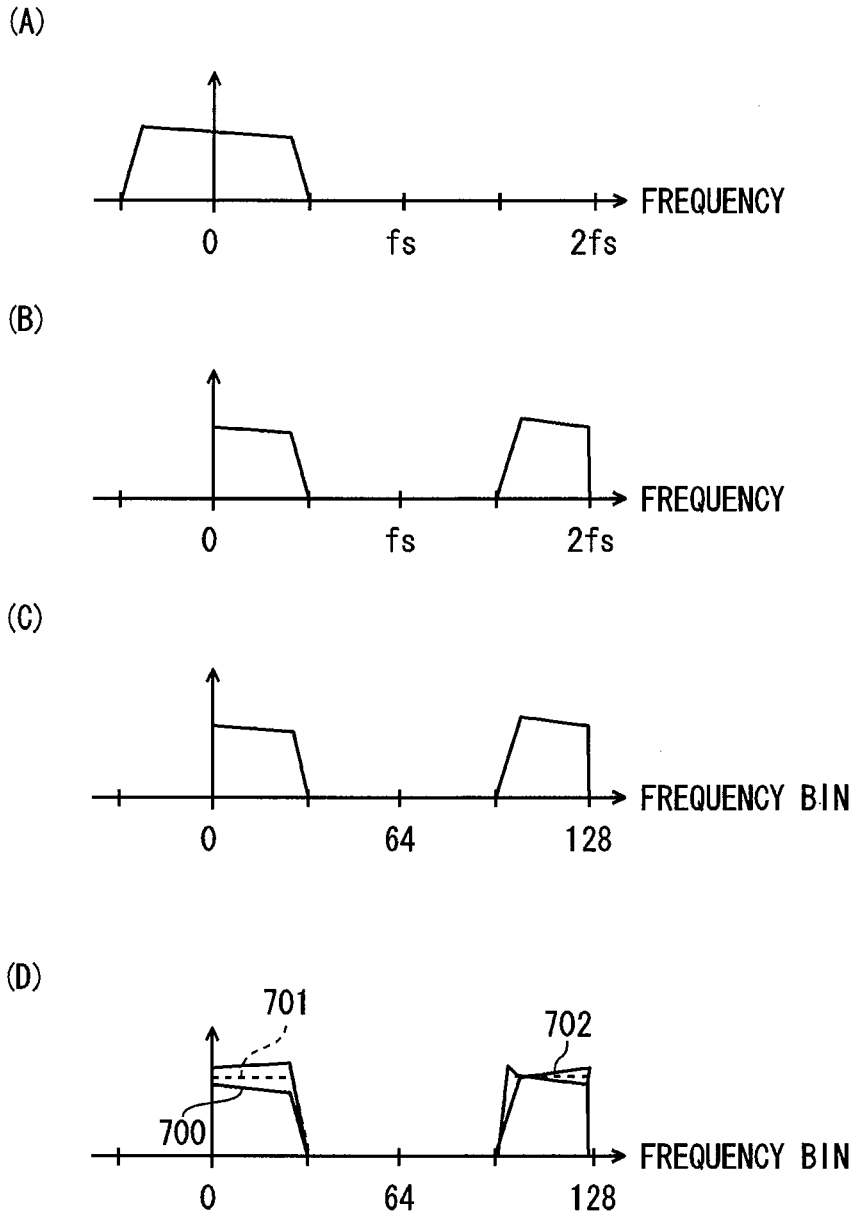

(A)
FREQUENCY
0
fs
2fs
(B)
FREQUENCY
0
fs
2fs
(C)
FREQUENCY BIN
0
64
128
(D)
701
702
700
FREQUENCY BIN
0
64
128

FIG. 6

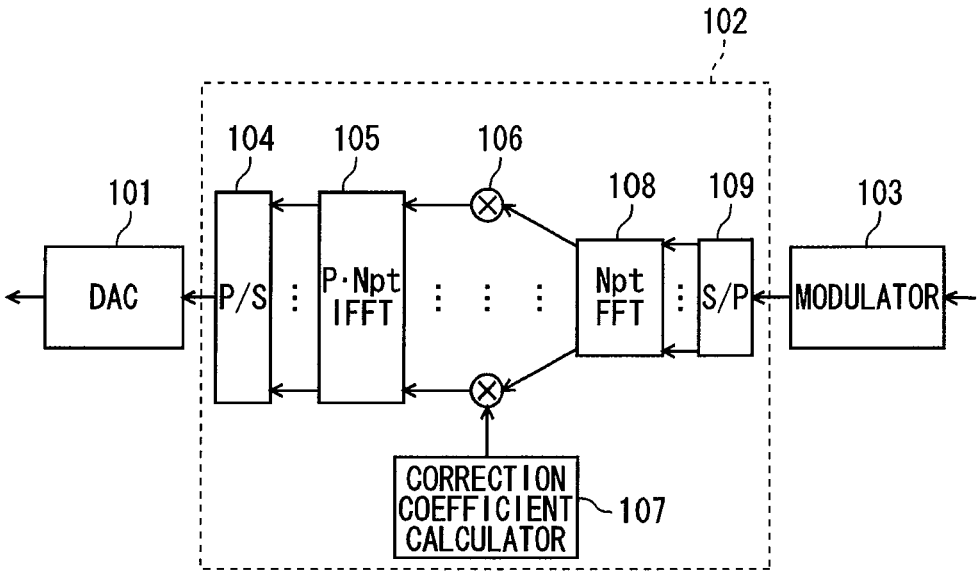

102
104
105
106
101
108
109
103
DAC
P/S
P·Npt IFFT
Npt FFT
S/P
MODULATOR
CORRECTION COEFFICIENT CALCULATOR
107

FIG. 7

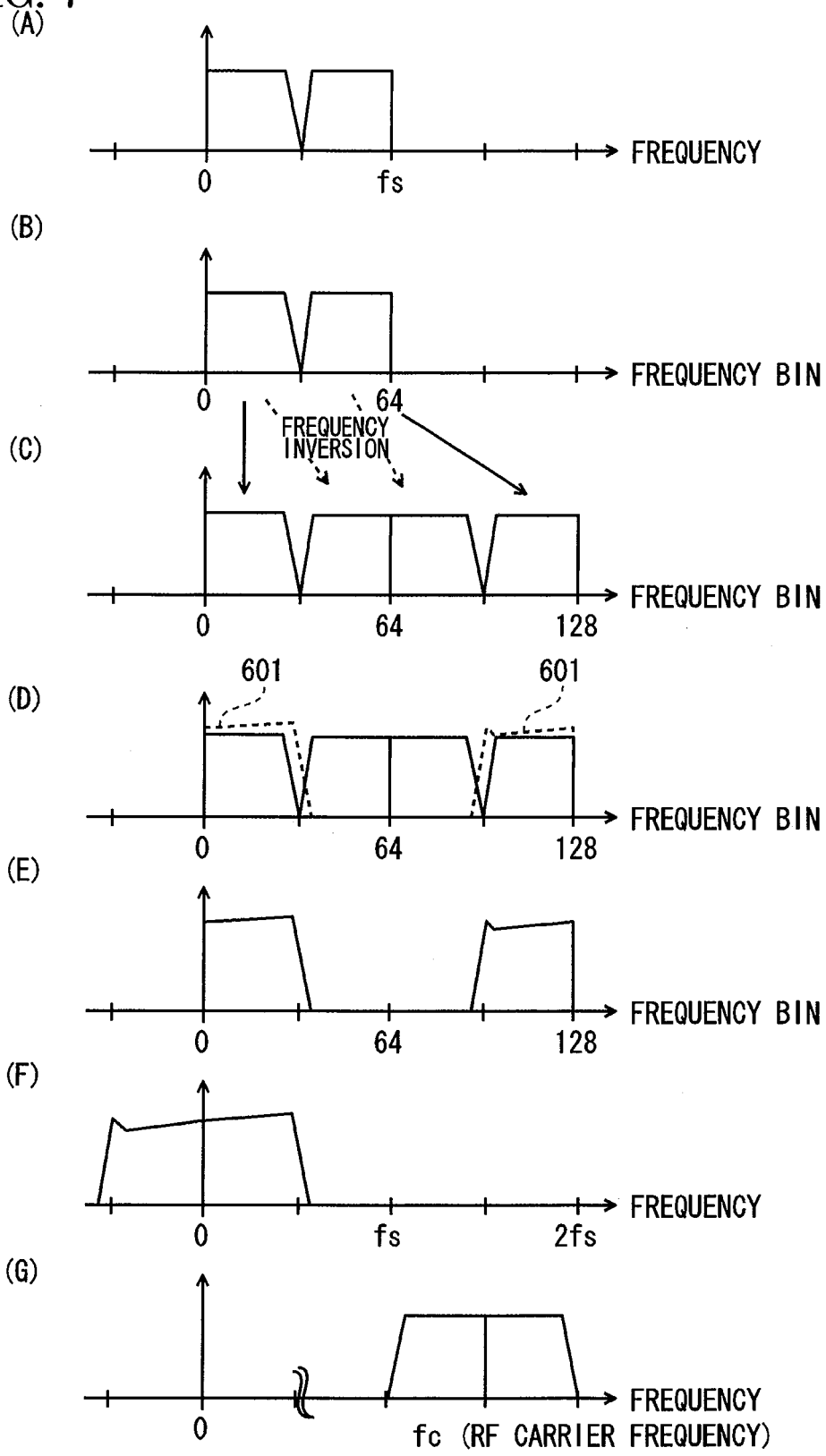
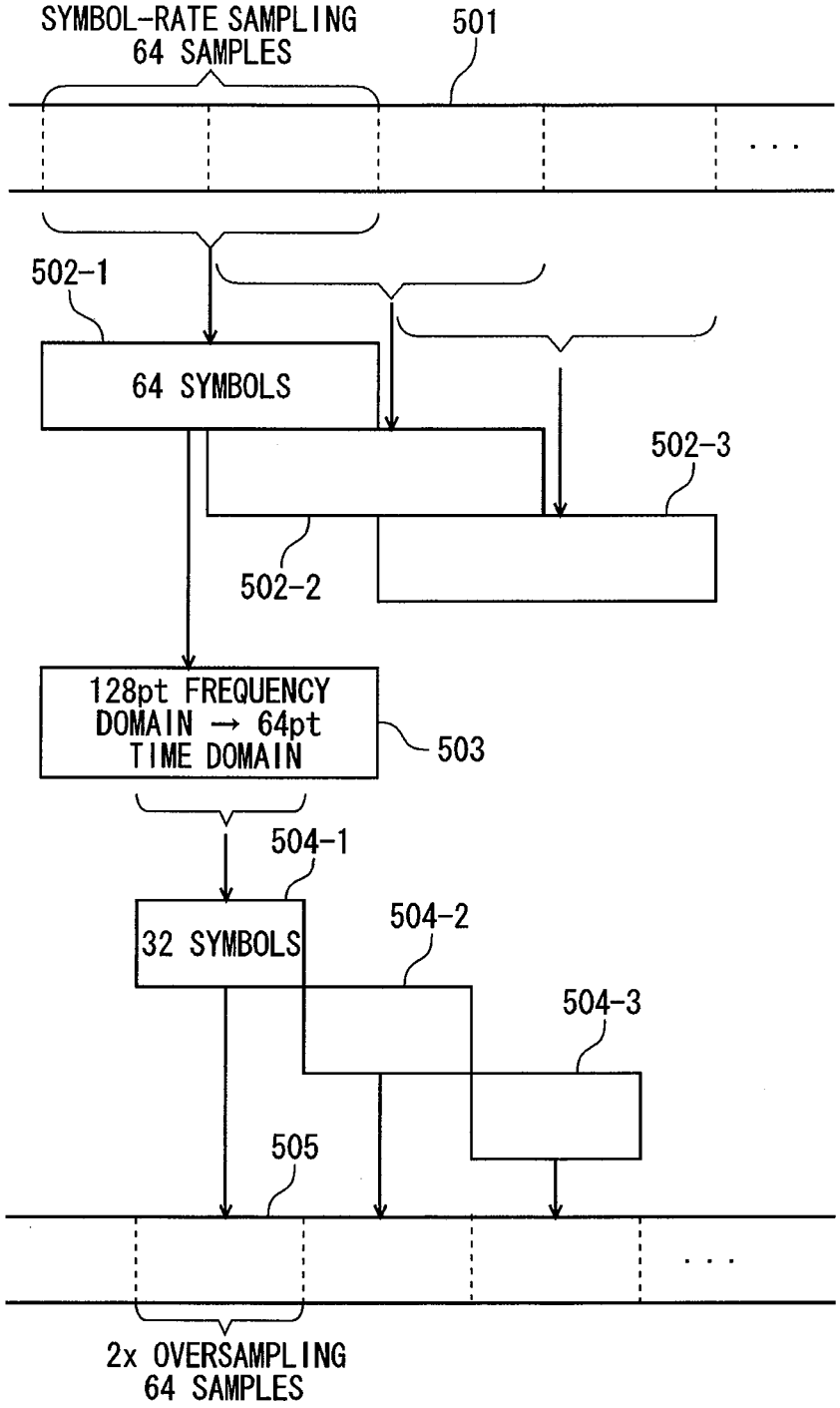

(A)
FREQUENCY
0
fs
(B)
FREQUENCY BIN
0
64
(C)
FREQUENCY INVERSION
FREQUENCY BIN
0
64
128
(D)
601
601
FREQUENCY BIN
0
64
128
(E)
FREQUENCY BIN
0
64
128
(F)
FREQUENCY
0
fs
2fs
(G)
FREQUENCY
0
fc (RF CARRIER FREQUENCY)

FIG. 8


SYMBOL-RATE SAMPLING
64 SAMPLES
501
502-1
64 SYMBOLS
502-3
502-2
128pt FREQUENCY DOMAIN → 64pt TIME DOMAIN
503
504-1
32 SYMBOLS
504-2
504-3
505
2x OVERSAMPLING
64 SAMPLES

TRANSMISSION-RECEPTION DEVICE

TECHNICAL FIELD

The present invention relates to a transmission-reception device that transmits and receives a modulation signal using a single carrier transmission system.

BACKGROUND ART

In recent years, a service has been considered that provides end-users with data which includes a variety of large volume content using high-resolution images (including moving images and still images) or voices through wireless communications.

Particularly, in order to transmit large volume data ranging several G (Giga) bits at high speed, a wireless communication system has been considered which performs a high speed transmission of several G bps using a millimeter wave band including 60 GHz band. In particular, in the IEEE (Institute of Electrical and Electronics Engineering), a standardization work for IEEE 802.15.3c, for example, as a wireless PAN, or for IEEE 802.11ad, for example, as a wireless LAN, has been performed.

For example, in a single carrier communication using a millimeter wave band studied in the IEEE 802.11 ad, a PSK or a QAM modulation signal is transmitted at the speed of 1.76 G symbol/sec. 1 symbol time is as short as 0.57 nsec.

On the other hand, in a radio frequency (RF) circuit in which a modulated baseband signal is up-converted into a 60 GHz band and transmitted from an antenna, broadband communication characteristics are required. Since the signal has a broadband with a bandwidth of 1.76 GHz, in order to achieve a transmission in which a signal distortion does not arise, it is required that passband characteristics of the RF circuit be flat all over the bands of the signal.

However, actually, it is difficult for a mixer or a power amplifier in which the signal is converted into radio frequency of 60 GHz to have flat passband characteristics all over the bands of the signal.

As a method of correcting a distortion of passband characteristics in an RF circuit, a pre-distortion method using a digital baseband signal is known. In this method, the passband characteristics of the RF circuit are measured in advance to obtain a digital filter coefficient which is inverse characteristics of a measured result, and then a distortion correction is performed to cause the passband characteristics to be flat by filtering a transmission signal when the signal passes through the RF circuit.

As a wireless communication system using the pre-distortion, for example, Patent Literature 1 and Patent Literature 2 are known. The wireless communication device disclosed in Patent Literature 1 detects frequency distortion characteristics of a loopback signal from a transmission side to a reception side in the RF circuit, holds a time domain signal to which a difference spectrum from ideal characteristics is transformed by means of an inverse Fourier transform, and corrects the distortion by adding the signal to an FIR filter at the time of transmission.

In addition, in a digital wireless communication device disclosed in Patent Literature 2, the pre-distortion is performed in a frequency domain signal. In the digital wireless communication device, the time domain signal which is oversampled L times by inserting a zero sample is transformed by means of an N point Fourier transform, and then is weighted in a frequency domain. After the weighting, the digital wireless communication device shifts a frequency bin to change a center frequency, and transforms the signal to the time domain signal by means of an N point inverse Fourier transform and then outputs the transformed signal.

CITATION LIST

Patent Literature

Patent Literature 1: JP-A-2000-244370
Patent Literature 2: JP-A-2010-252178

SUMMARY OF INVENTION

Technical Problem

However, in a wireless communication device in the related art described above, there is a problem as follows. Specifically, in the related art described above, with respect to a signal in which a symbol of a transmission signal is oversampled (interpolation) in a DA converter, it is necessary to provide a pre-distortion filter.

That is, when the wireless communication device in the related art is applied to a millimeter wave communication, for example, even in a case of two times oversampling, it is necessary to use a digital filter with respect to a time domain signal of 3.52 Gsps (samples per second).

In order to increase a frequency resolution in passband characteristics of an RF circuit, which are corrected using an interpolation filter and a pre-distortion filter, a circuit size increases because an FIR filter of dozen taps is required. In addition, a processing clock speed is required to be increased for a filter operation.

The present invention is made in consideration of such circumstances, and an object thereof is, even in a baseband signal having a broad signal-bandwidth due to a high symbol speed, to provide a transmission-reception device which accurately corrects the passband characteristics without increasing the circuit size.

Solution to Problem

A transmission-reception device according to the present invention includes: a radio frequency section that performs a frequency conversion on a signal which is modulated using a single carrier transmission system; a correction coefficient multiplier that multiplies a frequency domain signal by a distortion correction coefficient in the frequency conversion of the radio frequency section to correct a distortion; a first transformer that converts a time domain signal into a frequency domain signal at a time of reception, and converts the frequency domain signal which is distortion-corrected by the correction coefficient multiplier into a time domain signal at a time of transmission; and a second transformer that converts a time domain signal into a frequency domain signal at a time of transmission, and converts the frequency domain signal which is distortion-corrected by the correction coefficient multiplier into a time domain signal at a time of reception.

Advantageous Effects of Invention

According to the present invention, in a distortion correction at the time of transmission, since a correction coefficient multiplier, a first transformer and a second transformer may be shared at the time of reception, passband characteristics may be corrected with high accuracy without significantly increasing the circuit size at the time of transmission.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a block diagram illustrating an overall configuration of a transmission-reception device.

FIG. **2** is a block diagram illustrating an internal configuration of a distortion correction section.

FIG. **3** is a diagram illustrating an example of a frame format of a transmission signal.

FIG. **4** is a block diagram illustrating an internal configuration of a distortion correction section at the time when a calibration is performed for transmission distortion characteristics.

FIG. **5** indicates diagrams illustrating signals of each section in the distortion correction section using spectrums at the time of a calibration, in which (A) illustrates a spectrum of a baseband signal input to an AD converter, (B) illustrates a spectrum of a signal after two times oversampling of the baseband by the AD converter, (C) illustrates a spectrum of a frequency domain signal to which a sample sequence is transformed by FFT with 128 points, and (D) illustrates a spectrum of a frequency domain signal corresponding to inverse characteristics of distortion characteristics.

FIG. **6** is a block diagram illustrating an internal configuration of a distortion correction section at the time of transmission.

FIG. **7** indicates diagrams illustrating signals at each signal inside a distortion correction section at the time of transmission using spectrums, in which (A) illustrates a spectrum of a modulation signal with a symbol speed of fs from a modulator, (B) illustrates a spectrum of a frequency domain signal to which a sample sequence is transformed by FFT with 64 points, (C) illustrates a spectrum of a frequency domain signal where a frequency band is expanded by a two times oversampling for each frequency bin, (D) illustrates a spectrum of a signal of a transmission distortion correction coefficient, (E) illustrates a spectrum of a frequency domain signal after multiplication of a transmission distortion correction coefficient, (F) illustrates a spectrum of a baseband signal, and (G) illustrates a spectrum of a frequency domain signal in which a distortion in a transmission side of an RF section is corrected.

FIG. **8** is a diagram illustrating an example of a processing unit of a signal that is subject to correction.

DESCRIPTION OF EMBODIMENTS

Embodiments of a transmission-reception device according to the present invention will be described with reference to the drawings. The transmission-reception device according to the present invention is applied to a transmission-reception device which transmits and receives a wireless signal having a millimeter wave band.

(A Signal Format)

FIG. **3** is a diagram illustrating an example of a frame format of a transmission signal. The frame format of the transmission signal has a configuration including a preamble **401**, a channel estimation field **402**, a guard interval (GI) **403** and data **404**.

The preamble **401** includes a waveform which is obtained by repeating a known signal waveform multiple times. For example, in the preamble **401**, by setting a signal waveform where a Golay sequence with 128 bits having excellent correlation characteristics is subject to BPSK modulation as one unit, the waveform is used which is obtained by repeating one unit of the signal waveform multiple times. The transmission-reception device according to the invention, obtains the repetition of the known waveform using correlation detection, and uses the repetition for synchronization processing including at least one or more tasks among frame detection, a gain control and a synchronization of a carrier frequency.

The channel estimation field **402** similarly including a plurality of the known signal waveforms is used for an estimation of a distortion in a channel in the transmission-reception device according to the invention. For example, in the channel estimation field **402**, a signal waveform is used where a Golay sequence with 128 bits and a complementary sequence of the Golay sequence are subjected to the BPSK modulation.

The guard interval **403** is inserted as a divider for the data **404**. In the guard interval **403** also, the known signal waveform, for 64 bits is modulated.

The data **404** includes a PSK or QAM modulation symbol sequence to which a data bit sequence which is encoded for error correction for each block unit is modulated.

A symbol sequence of a transmission signal which is digitally modulated using a frame format (signal format) described above is filtered by using a root raised cosine filter as a transmission band limitation filter, and is converted into an analog baseband signal by a DA converter. The baseband signal is converted into a single carrier radio frequency signal in a radio frequency (RF) section (refer to FIG. **1**) and is transmitted from an antenna.

(Configuration of Transmission-Reception Device)

FIG. **1** is a block diagram illustrating an overall configuration of a transmission-reception device **10**. The transmission-reception device **10**, as illustrated in FIG. **1**, has a configuration including an antenna **301**, a radio frequency section (RF section) **302**, an AD converter **201**, a synchronization section **303**, a distortion correction section **102**, a demodulator **304**, a DA converter **101**, and a modulator **103**.

In addition, the RF section **302** includes a configuration of a transmission side for an up-conversion of a signal subjected to the single carrier modulation by the modulator **103**, and a configuration of a reception side for a down-conversion of the single carrier radio frequency signal received by the antenna **301**.

At the time of transmission, the distortion correction section **102** corrects transmission distortion characteristics that are added to a symbol sequence which is digitally modulated (single carrier modulation) in the modulator **103** by the transmission side of the RF section **302**, and outputs the result to the DA converter **101**.

The DA converter **101** converts the output signal from the distortion correction section **102** into the analog baseband signal. The transmission side of the RF section **302** up-converts the analog baseband signal into the single carrier radio frequency signal, and transmits it via the antenna **301**.

At the time of reception, the reception side of the RF section **302** down-converts the single carrier radio frequency signal received by the antenna **301** into a baseband signal. The reception side of the RF section **302** outputs the baseband signal to the AD converter **201**. The AD converter **201** converts the baseband signal into the digital signal by sampling the output signal from the reception side of the RF section **302**.

The synchronization section **303** performs a synchronization processing including at least one or more tasks among frame detection, a gain control of the RF section **302**, and a synchronization of a carrier frequency, using the preamble **401** in the reception signal which is a converted digital signal.

The distortion correction section **102** estimates a channel distortion using the channel estimation field **402**, according to a frame timing detected in the synchronization section **303**,

and corrects distortion characteristics of a channel of subsequent data **404** and then outputs a symbol sequence.

The demodulator **304** inputs the symbol sequence which is output from the distortion correction section **102** and determines a signal point to demodulate the data, and reproduces transmission data.

FIG. **2** is a block diagram illustrating an internal configuration of the distortion correction section **102**. The distortion correction section **102**, as illustrated in FIG. **2**, has a configuration including a switching section C**1**, a parallel/serial converter **104**, a PN point inverse-Fourier/Fourier transformer **105**, a correction coefficient multiplier **106** (**106-1** to **106-***n*), a correction coefficient calculator **107**, a distortion estimator **202**, an N point Fourier/inverse-Fourier transformer **108**, a serial/parallel converter **109**, and a switching section C**2**.

The switching section C**1** switches the paths in order to output a reception signal from the synchronization section **303** to the parallel/serial converter **104** at the time of reception or calibration, and in order to output a transmission signal from the parallel/serial converter **104** to the DA converter **101** at the time of transmission.

The parallel/serial converter **104** converts a serial signal into a parallel signal at the time of reception or calibration and converts the parallel signal into the serial signal at the time of transmission.

The PN point inverse-Fourier/Fourier transformer **105** as a first transformer performs a Fourier transform or an inverse Fourier transform by reversing the sign of rotate operation with a unit of a frequency domain signal or a time domain signal having P×N points.

More specifically, the PN point inverse-Fourier/Fourier transformer **105** performs a Fourier transform with a time domain signal having P×N points as a unit at the time of reception or calibration and converts the transformed signal into a frequency domain signal having P×N points.

In addition, the PN point inverse-Fourier/Fourier transformer **105** performs an inverse Fourier transform with a unit of the frequency domain signal having P×N points at the time of transmission and converts the transformed signal into the time domain signal having P×N points.

The switching section C**2** switches the paths in order to output the reception signal from the serial/parallel converter **109** to the demodulator **304** at the time of reception or calibration, and in order to output the transmission signal from the modulator **103** to the serial/parallel converter **109** at the time of transmission.

The serial/parallel converter **109** converts the parallel signal into the serial signal at the time of reception or calibration and converts the serial signal into the parallel signal at the time of transmission.

The N point Fourier/inverse-Fourier transformer **108** as a second transformer performs a Fourier transform or an inverse Fourier transform, as it can be realized by reversing the sign of the rotate operation, with a unit the time domain signal or the frequency domain signal having N points.

Specifically, the N point Fourier/inverse-Fourier transformer **108** performs an inverse Fourier transform with the frequency domain signal having N points as a unit at the time of reception or calibration and converts the transformed signal into the time domain signal having N points.

In addition, the N point Fourier/inverse-Fourier transformer **108** performs a Fourier transform with a unit of the time domain signal having N point and converts the transformed signal into a frequency domain signal having N points at the time of transmission.

Each section can be shared with the distortion correction section **102** by changing a processing direction of the signal in any timing among the time of transmission, reception and calibration.

Next, an operation of the distortion correction section **102** will be described in detail.

(Operation at the Time of Calibration)

The operation of the distortion correction section **102** at the time of calibration will be described. In the calibration, transmission distortion characteristics in the transmission side of the RF section **302** are measured and a transmission distortion correction coefficient for correcting the transmission distortion characteristics is obtained. In addition, the reception distortion characteristics in the reception side of the RF section **302** are already calibrated, a reception distortion correction coefficient for correcting the reception distortion characteristics is considered to be obtained in advance.

Furthermore, in the calibration of the reception distortion characteristics, for example, a reference signal from a measuring instrument is input to the reception side of the RF section **302**, and the reception distortion characteristics are measured using a method similar to the method described below and thereby the reception distortion correction coefficient may be obtained.

FIG. **4** is a block diagram illustrating an internal configuration of the distortion correction section **102** at the time of calibration of the transmission distortion characteristics. Further, in FIG. **4**, the switching section C**1** is not illustrated. At the time of calibration, the DA converter **101** inputs the reference signal having the known signal waveform from outside of the transmission-reception device **10** and outputs the signal to the transmission side of the RF section **302**, and further inputs the signal which is subjected to the loopback to the AD converter **201** via the reception side of the RF section **302**. In other words, the loopback signal from the transmission side of the RF section **302** to the reception side of the RF section **302** is input to the RF section **302**.

Here, any signal may be used as the reference signal if it is a signal having the known signal waveform, for example, a modulation signal of the preamble **401** of the transmission signal may be used. Alternatively, any sinusoidal wave signal with arbitrary frequency may be used. It is preferable to use a broadband signal in which signal band frequency characteristics of the transmission signal can be measured or a signal to which a narrowband signal of the sinusoidal wave subjected to frequency-sweep in the signal band.

The AD converter **201** inputs the reference signal which is a loopback signal in the RF section **302** to perform a sampling and outputs a digital signal after the sampling to the parallel/serial converter **104** via the synchronization section **303** and the switching section C**1**.

The parallel/serial converter **104** converts the input digital signal (serial signal) into the parallel signal and outputs the parallel signal to the PN point inverse-Fourier/Fourier transformer **105**.

The PN point inverse-Fourier/Fourier transformer **105** performs a Fourier transform with respect to the time domain signal which is an input signal from the parallel/serial converter **104**, and converts the transformed signal into the frequency domain signal. The PN point inverse-Fourier/Fourier transformer **105** selects a signal with a signal band from the frequency domain signal to output the signal to the distortion estimator **202**.

The distortion estimator **202** corrects the frequency domain signal with the input signal band using the reception distortion characteristics of the RF section **302**, which are obtained in advance, and then obtains a difference vector

between the frequency domain signal after the correction and the frequency domain signal of the known reference signal, for each frequency bin (range). The difference vector corresponds to the transmission distortion characteristics in the transmission side of the RF section **302**.

The correction coefficient calculator **107** obtains a correction vector which is inverse characteristics of the estimated transmission distortion characteristics, based on the transmission distortion characteristics estimated by the distortion estimator **202**, and holds the transmission distortion correction coefficient which corresponds to the correction vector. Furthermore, in the correction coefficient calculator **107**, the correction vector may be weighted for each frequency bin using the frequency domain characteristics of a root raised cosine filter which is obtained in advance as a transmission band limitation filter.

FIG. **5** shows diagrams illustrating signals of each section in the distortion correction section **102** using spectrums at the time of calibration. The reference signal for the calibration is understood as a signal which has the same bandwidth fs (Hz) as the transmission signal.

FIG. **5**(A) illustrates a spectrum of the baseband signal input to the AD converter **201**. The baseband signal is a complex signal and shows a spectrum having the bandwidth fs (Hz) with centering on DC component (0 Hz).

FIG. **5**(B) illustrates a spectrum of a signal after two times oversampling of the baseband by the AD converter **201**. A sampling speed is 2 fs (Hz) and a repetition (aliasing) occurs around fs (Hz).

FIG. **5**(C) illustrates a spectrum of the frequency domain signal to which a sample sequence is transformed by means of FFT with 128 points. A horizontal axis illustrates a frequency bin (K=0 to 127) where 2 fs (Hz) is discretized to 128 points. The signal band exists in the frequency bin ranging k=0 to 31 and k=96 to 127.

As illustrated in FIG. **5**(D), with respect to the frequency bin equivalent to the signal band of 64 points, a difference between signal band characteristics **700** (refer to FIG. **5**(C)) and ideal frequency characteristics **701** (dotted line) becomes the transmission distortion characteristics. The correction coefficient calculator **107** obtains a transmission distortion correction coefficient **702** (solid line) which is the inverse characteristics of the transmission distortion characteristics, and stores it in the correction coefficient calculator **107**.

Here, an operation of calibration in the distortion correction section **102** will be described using numerical expressions.

It is assumed that there are the transmission signal x(t), the loopback reception signal r(t), the pass band characteristics of the transmission side of the RF section **302** h_t x(t), and the pass band characteristics of the reception side of the RF section **302** hr x(t).

In addition, if assumed that values where the transmission signal x(t), the loopback reception signal r(t), the pass band characteristics of the transmission side of the RF section **302** h_t x(t), and the pass band characteristics of the reception side of the RF section **302** h_r x(t) are subjected to the Fourier transform are repectively X(f), R(f), H_tx(f), H_rx(f), then expression (1) is obtained.

[Expression 1]

$$R(f)=H_rx(f)H_tx(f)X(f) \tag{1}$$

In addition, the reference signal for calibration is set to x_ref(t), a value after x_ref(t) is subjected to the Fourier transform to is set to X_ref(f), the reference signal subjected to the loopback to the reception side of the RF section **302** is set to r_ref(t), and a value after r_ref(t) is subjected to the Fourier transform is set to R_ref(f), and then the pass band characteristics H(f) of the RF section **302** can be obtained by expression (2).

[Expression 2]

$$H(f)=R_\mathrm{ref}(f)/X_\mathrm{ref}(t) \tag{2}$$

Here, if the pass band characteristics H_rx(f) in the reception side of the RF section **302** which are obtained in advance are used, communication band characteristics H_tx(f) are obtained as illustrated in expression (3).

[Expression 3]

$$H_tx(f)=H(f)/H_rx(f) \tag{3}$$

That is, 1/H_tx(f) can be obtained as the transmission distortion coefficient **702** (refer to FIG. **7**) which is the inverse characteristics of transmission distortion characteristics, by the calibration of the distortion correction section **102**.

(Operation at the Time of Transmission)

Next, an operation which corrects the transmission signal using the transmission distortion correction coefficient which is obtained at the time of calibration by the distortion correction section **102** will be described. FIG. **6** is a block diagram illustrating an internal configuration of the distortion correction section **102** at the time of transmission. In addition, the switching section C**2** is not illustrated in FIG. **6**.

At the time of transmission, the serial/parallel converter **109** inputs the symbol sequence (a serial signal) which is modulated at a symbol speed of fs (Hz) by the modulator **103** via the switching section C**2**, and converts the symbol sequence into the parallel signal for each N symbols.

The N point Fourier/inverse-Fourier transformer **108** performs the Fourier transform for an N symbol signal which is the input parallel signal and converts the transformed signal into the frequency domain signal having N points, which can be configured by a complex vector for each frequency bin.

In addition, the N point Fourier/inverse-Fourier transformer **108** expands the band of the frequency domain signal having N points to P×N points in order to enable the P times oversampling(P>1) which is necessary for the DA converter **101** to perform an analog signal conversion.

More specifically, the N point Fourier/inverse-Fourier transformer **108** duplicates the complex vector in the signal band of the frequency bin into another band of the same frequency bin in order to generate an aliasing component of the signal band equivalent to the oversampling.

The correction coefficient multiplier **106**, for each frequency bin, multiplies the frequency domain signal which is band-expanded to P×N points by means of the inverse Fourier transformer **108**, by the transmission distortion correction coefficient obtained by the correction coefficient calculator **107**. The correction coefficient multiplier **106** outputs the result of the multiplication to the PN point inverse-Fourier/Fourier transformer **105**.

The PN point inverse-Fourier/Fourier transformer **105** performs the inverse Fourier transform on the result of the multiplication from the correction coefficient multiplier **106**, that is, the frequency domain signal having P×N points multiplied by the transmission distortion correction coefficient, and converts the transformed signal into the time domain signal. The PN point inverse-Fourier/Fourier transformer **105** outputs the time domain signal to the parallel/serial converter **104**.

The time domain signal is a sample sequence which is P times oversampled with respect to the symbol sequence which of the original N symbols. The sample sequence with P×N samples is converted into the serial signal in the parallel/serial converter **104**.

The parallel/serial converter **104** outputs the sample sequence in a central part where the first and the last several samples which are affected by a waveform truncation due to FFT and IFFT are removed among P×N samples, for example, the sample sequence with P×N/2 samples in central part.

In addition, in the transmission-reception device **10**, the N symbol which is subject to correction, among the symbol sequence input from the modulator **103** to the distortion correction section **102** is input while being overlapped for each N/2 symbol. Accordingly, continuity in the sample sequence output from the distortion correction section **102** is maintained.

FIG. **7** shows diagrams illustrating each signal inside the distortion correction section **102** using spectrums. FIG. **7**(A) illustrates a spectrum of the modulation signal with a symbol speed fs (Hz) from the modulator **103**. Since the sample sequence has the same symbol speed fs (Hz) and sample speed, the repetition occurs at fs/2 (Hz) in FIG. **7**(A).

FIG. **7**(B) illustrates a spectrum of the frequency domain signal to which the sample sequence is transformed by means of FFT with 64 points. The horizontal axis illustrates the frequency bin (k=0 to 63) in which fs (Hz) is discretized to 64 points.

FIG. **7**(C) illustrates the spectrum of the frequency domain signal which is band-expanded by two times oversampling for each frequency bin. As illustrated in FIG. **7**(C), the N point Fourier/inverse-Fourier transformer **108** expands the band of the frequency domain signal in order for the DA converter **101** to perform two times (P=2) oversampling.

In other words, in a case where the frequency band is expanded to 128 points due to the two times oversampling, the N point Fourier/inverse-Fourier transformer **108** duplicates a signal band component with respect to the frequency bin which is an aliasing frequency, in order to generate a signal aliasing component of the original signal band.

FIG. **7**(D) illustrates a spectrum of a signal of the transmission distortion correction coefficient **601**. As illustrated in FIG. **7**(D), if the frequency domain signal having 128 points, in which an oversampling is performed by the correction coefficient multiplier **106** is multiplied by the transmission distortion correction coefficient **601**, the frequency domain signal after the transmission distortion is corrected can be obtained (refer to FIG. **7**(E)). FIG. **7**(E) illustrates a spectrum of the frequency domain signal after the multiplication of the transmission distortion correction coefficient. In a case where the root raised cosine filter (RRC filter) is also included in the transmission distortion correction coefficient **601**, the above multiplication also acts as the transmission band limitation filter.

In the PN point inverse-Fourier/Fourier transformer **105**, the corrected frequency domain signal is converted into the time domain signal by means of the inverse Fourier transform in the 128 point IFFT, and is output to the DA converter **101** via the switching section C**1**. In the DA converter **101**, when the input time domain signal is converted into the analog signal, a spectrum of the baseband signal illustrated in FIG. **7**(F) can be obtained.

In addition, in the RF section **302**, as illustrated in FIG. **7**(G), the baseband signal is modulated using a single carrier frequency fc. FIG. **7**(G) illustrates the spectrum of a frequency domain signal in which a distortion in the transmission side of the RF section is corrected.

Here, an operation of the distortion correction at the time of transmission in the distortion correction section **102** will be described using numerical expressions.

The correction coefficient multiplier **106** obtains a signal X" (f) represented by expression 4 (refer to FIG. **7**(E)) in such a way of multiplying a frequency domain signal x'(f) (refer to FIG. **7**(D)), in which the Fourier transform and the oversampling are performed on a transmission signal x (t), by a frequency domain representation C_filt (f) having the transmission RRC filter characteristics, and a correction coefficient 1/H_tx(f) which corrects the passband characteristics of the transmission side of the RF section **302**.

[Expression 4]

$$X''(f)=X'(f)C_filt(f)/H_tx(f) \tag{4}$$

The PN point inverse-Fourier/Fourier transformer **105** performs the inverse Fourier transform to transform the frequency domain signal X"(f) obtained by the expression 4 to the time domain signal x"(t) (refer to FIG. **7**(F)). The time domain signal x"(t) is transmitted from the antenna **301** via the transmission side of the RF section **302**. The signal x'"(t) is represented by expression 5.

[Expression 5]

$$x'''(t)=x''(t)*h_tx(t) \tag{5}$$

A symbol "k" represents a convolution operation. If the Fourier transform is performed on the signal x'", and the signal is represented by the frequency domain, it is represented by expression 6.

[Expression 6]

$$\begin{aligned} X'''(f) &= X''(f)\mathrm{H_tx}(f) \\ &= \mathrm{X'C_filt}(f) \end{aligned} \tag{6}$$

In the transmission-reception device **10**, a signal distortion which occurs in the transmission side of the RF section **302** can be corrected and a signal multiplied by a transmission filter can be transmitted (refer to FIG. **7**(G)). FIG. **7**(G) illustrates a spectrum of a signal in which a distortion in the transmission side of the RF section **302** is corrected.

FIG. **8** is a diagram illustrating an example of a processing unit of a signal that is subject to correction. In FIG. **8**, a sample (symbol) sequence **501** of the symbol-rate sampling (1× oversampling) in which the symbol speed and the sample speed is the same, is input. The processing unit of the signal subject to the correction is set to N=64 symbols.

The serial/parallel converter **109** selects a sample sequence **502-1** of 64 samples which are equivalent to 64 symbols from the sample sequence **501**. The serial/parallel converter **109** selects sample sequences **502** (**502-1**, **502-2** and **502-3**) which are overlapped for each N/2=32 symbols (32 samples) as processing units.

With respect to each selected sample sequence **502**, the 64 point Fourier transform and the distortion correction are performed by the distortion correction section **102** and then the sample sequence is converted into the time domain signal **503** with 128 samples (64 symbols) where the two times oversampling is performed, by means of the 128 point inverse Fourier transform.

From here, a partial sample sequence **504-1** out of the 64 samples (32 symbols) in the central part is selected and output. The sample sequences **502-2** and **502-3** are also processed in the same way, and are converted into sample sequences **504-2** and **504-3**.

These sample sequences **504-1**, **504-2**, and **504-3** are concatenated, and the sample sequence **505** in which the over

sampling is performed at the speed of P=two times with respect to the symbol speed is output while a continuity being maintained.

As described above, the transmission-reception device **10** according to the invention performs an FDE (Frequency Domain Equalization) using the distortion correction section **102** as an equalizer at the time of reception, and measures a passband of the RF section at the time of calibration. Furthermore, according to the transmission-reception device **10**, the transmission-reception device is used as the frequency domain filter which performs an interpolation (oversampling) and a pre-distortion (distortion correction) at the time of transmission.

As a result, according to the transmission-reception device **10**, it is possible to accurately correct the passband characteristics of the transmission RF circuit without significantly increasing the size of the circuit. Therefore, even in a case of the baseband signal in which the signal bandwidth ranges over the broadband due to the high symbol speed, it is possible to accurately correct the passband characteristics without significantly increasing the size of the circuit. In addition, it is possible to decrease the clock speed by parallelizing the signal processes.

Although a variety of embodiments has been described with reference to the drawings, it is needless to say that the invention is not limited to the examples. It is apparent to those skilled in the art that various modification examples and improvements may be obtained by contemplations within the scope of the disclosed claims, and thereby it is also understood that all those fall within the technical scope of the invention without any doubt.

In addition, in each configuration in the embodiments, it may be realized by an LSI which is an integrated circuit. The LSI may be integrated into a single chip, or may be integrated into a single chip by including a part or all of each configuration. Here, it is referred to as the LSI, it is also referred to as an IC, a system LSI, a super LSI or an ultra LSI depending on the difference in the degree of integration.

In addition, the method of circuit integration is not limited to the LSI, a dedicated circuit or a general-purpose processor may be used for the circuit integration. Furthermore, an FPGA (Field Programmable Gate Array) which is programmable after the LSI manufacturing, or a reconfigurable processor in which connecting and resetting of circuit cells are reconfigurable, may be used.

In addition, the functional blocks may be operated using a DSP or a CPU, for example. Furthermore, the processing steps can be recorded on a recording medium as a program and to be performed.

Furthermore, if there appears a circuit integration technology which replaces the LSI owing to an advanced semiconductor technology or another derivative technology, the functional blocks may be integrated using such a technology.

In addition, although in the above-described embodiment, a case of signal transmission and reception of a millimeter waveband wireless signal has been described, the invention may also be applied to a wireless signal including a centimeter waveband signal in the same manner.

Furthermore, the invention is widely applicable to the overall wireless communication devices including the mobile communication which requires a small sized circuit and low power consumption, as a transmission distortion correction circuit used in a single carrier communication.

The present application is based on Japanese Patent Application No. 2011-075832 filed on Mar. 30, 2011, the contents of which are incorporated herein by reference.

INDUSTRIAL APPLICABILITY

The present invention is useful because, in a transmission-reception device that transmits and receives a signal which is modulated using a single carrier transmission system, even in a case of a baseband signal in which a signal bandwidth ranges over a broadband due to a high symbol speed, it is possible to accurately correct passband characteristics without significantly increasing a size of a circuit.

REFERENCE SIGNS LIST

10: TRANSMISSION-RECEPTION DEVICE
101: DA CONVERTER
102: DISTORTION CORRECTION SECTION
103: MODULATOR
104: PARALLEL/SERIAL CONVERTER
105: PN POINT INVERSE-FOURIER/FOURIER TRANSFORMER
106: CORRECTION COEFFICIENT MULTIPLIER:
107: CORRECTION COEFFICIENT CALCULATOR
108: N POINT FOURIER/INVERSE-FOURIER TRANSFORMER
109: SERIAL/PARALLEL CONVERTER
201: AD CONVERTER
202: DISTORTION ESTIMATOR
302: RADIO FREQUENCY (RF) SECTION
303: SYNCHRONIZATION SECTION
304: DEMODULATOR
401: PREAMBLE
402: CHANNEL ESTIMATION FIELD
403: GUARD INTERVAL (GI)
404: DATA
C**1**, C**2**: SWITCHING SECTION
601, **702**: CORRECTION COEFFICIENT

The invention claimed is:

1. A transmission-reception device, comprising:
a radio frequency section that performs a frequency conversion on a signal which is modulated using a single carrier transmission system;
a correction coefficient multiplier that multiplies a frequency domain signal by a distortion correction coefficient in the frequency conversion of the radio frequency section to correct a distortion;
a first transformer that converts a time domain signal into a frequency domain signal at a time of reception, and converts the frequency domain signal which is distortion-corrected by the correction coefficient multiplier into a time domain signal at a time of transmission; and
a second transformer that converts a time domain signal into a frequency domain signal at a time of transmission, and converts the frequency domain signal which is distortion-corrected by the correction coefficient multiplier into a time domain signal at a time of reception;
wherein the correction coefficient multiplier corrects transmission distortion characteristics in a transmission side of the radio frequency section at the time of transmission, and corrects reception distortion characteristics in the reception side of the radio frequency section and channel distortion characteristics at the time of reception.

2. The transmission-reception device according to claim **1**, wherein
the first transformer converts a loopback signal from a transmission side to a reception side of the radio frequency section, into a frequency domain signal, at a time of calibration.

3. The transmission-reception device according to claim 2, further comprising:

a distortion estimator that estimates distortion characteristics in the frequency conversion of the radio frequency section, based on the frequency domain signal into which the loopback signal is converted; and

a correction coefficient calculator that calculates a correction coefficient which is inverse characteristics of the distortion characteristics estimated by the distortion estimator, wherein

the correction coefficient multiplier multiplies the frequency domain signal by the correction coefficient calculated by the correction coefficient calculator, to correct the distortion at the time of transmission.

4. The transmission-reception device according to claim 1, wherein

the second transformer performs an oversampling where a signal having P×N points, where P>1, is obtained from a signal having N points, with respect to the frequency domain signal which is converted at the time of transmission, and

the correction coefficient multiplier multiplies the signal having P ×N points by a correction coefficient, to correct the distortion.

5. The transmission-reception device according to claim 4, wherein

the correction coefficient calculator calculates the correction coefficient by multiplying a coefficient for limiting a band.

6. The transmission-reception device according to claim 4, wherein

the first transformer performs a Fourier transform or an inverse Fourier transform with a unit of the frequency domain signal or the time domain signal having P×N points; and

the second transformer performs the Fourier transform or the inverse Fourier transform with a unit of the frequency domain signal or the time domain signal having N points, and

wherein the correction coefficient multiplier, located between the first transformer and the second transformer, is used as a frequency domain filter which performs an interpolation and a distortion correction at the time of transmission.

* * * * *